# COFIRING COAL AND BIOMASS AT AURORA POWER PLANT IN FAIRBANKS, ALASKA

By

Zackery Wright

APPROVED:

Dr. William Schnabel

Dr. Rorik Peterson

David Nicholls

Dr. David Nicholls
Advisory Committee Co-Chair

Daisy Huang

Dr. Daisy Huang
Advisory Committee Chair

Dr. Rorik Peterson
Chair, Department of Mechanical Engineering

March 19, 2016

Date

# COFIRING COAL AND BIOMASS AT AURORA POWER PLANT IN FAIRBANKS, ALASKA

A

PROJECT

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Zackery Wright, BS

Fairbanks, AK

May 2016

**Abstract**

Biomass energy has been a topic of great interest over the previous few years in Alaska; especially when various fuel sources were priced at a record high. Interior Alaska has the potential to utilize woody biomass to offset the use of coal in many of its power generating facilities. In this study, woody biomass in the form of clean aspen (*Populus tremuloides)* chips was cofired with Usibelli coal at the Aurora Power Plant facility in downtown Fairbanks, Alaska. Biomass was successfully cofired at low average rates of 2.4% and 4.81% of total energy value. Combustion gasses were analyzed using measuring probes in the exhaust stack. The 2.4% biomass test saw, on average, an increase in CO and $CO_2$ by 95ppm and 2%, respectively. A decrease in $NO_X$ of 1ppm was observed. During the 4.81% biomass test, CO increased by 83ppm, $NO_X$ decreased by 18ppm, and CO decreased by 1%. Opacity increased by 0.1% during the 2.4% biomass test and 0.17% during the 4.81% biomass test. The challenges facing a small scale facility in Interior Alaska are also presented. The testing exemplified that the use of biomass in stoker/grate boilers in Alaska is technically feasible with relative ease. No technical barriers to cofiring at low levels on an on-going basis were found at the Aurora Power Plant and this conclusion would likely hold true at similar facilities in interior Alaska.

**Dedication Page**

In dedication to my parents, Tisha and Joe.

Thanks for always keeping me pointed in the right direction.

## Table of Contents

## List of Figures

## List of Tables

## Acknowledgments

Special appreciation is given to the following people for their contributions, advice, and support in developing this research.

Daisy Huang (Alaska Center for Energy and Power/ University of Alaska: Fairbanks) and David Nicholls (US Forest Service) for being patient, always providing support, and for putting a lot of pieces together to make this project happen.

Rorik Peterson (University of Alaska: Fairbanks) and Bill Schnabel (Institute of Northern Engineering/ University of Alaska: Fairbanks) for providing feedback and helping with graduate committee requirements.

Aurora Power, Dave Fish, Marc Brazeau, and Steve Ferree, for providing the facility to do our testing and for being gracious hosts.

Chad Shumacher (Superior Pellet Fuels) for providing us with clean aspen chips and allowing us to tour the pellet mill and production facility.

US Forest Service for providing funding for the following research and supporting Alaskan energy causes.

## Introduction

Coal accounts for 29 percent of the electrical power capacity in Interior Alaska [1]. Unfortunately, coal fired power plants are one of the leading emitters of carbon dioxide ($CO_2$), nitrogen oxides ($NO_X$), and sulfur dioxide ($SO_2$) [2]. Previous research has shown that cofiring small amounts of biomass could significantly reduce some of these emissions [3]. Cofiring is simply the combustion of two different materials at the same time; usually coal and a biomass fuel. Interior Alaska has shown great potential to utilize a wide variety of biomass sources in cofiring operations [4]. Utilizing biomass could be an effective solution to reducing the emissions related to coal fired operations. Typically, biomass is cofired between 5 and 20% by mass of the coal in operational plants in the contiguous United States [5]. This study is one of the first introductions in Alaska. Cofiring of biomass also generally results in reduced ash content [6].

In Interior Alaska, power generation is done using "small" scale stoker system power plants with, typically, less than 30MW of generating capacity. Coal is spilled at a controlled rate onto a travelling grate and is combusted with air flow from below. The grate moves across the combustion chamber and drops any unburned ash and particles into a collection chamber. One excellent advantage to the stoker systems as candidates for cofire testing is that, when cofiring at low levels, the facilities require no large, or small, scale renovations [5]. Existing equipment can be used adequately with experienced operators managing the process.

Cofiring biomass has generally been tested at very large scale pulverized coal systems [3] [7] [8]. These power generation facilities pulverize the coal to very fine particle sizes, and then inject them into a combustion chamber. This creates another step in the process as both coal and biomass must be ground to an adequate particle size. Stoker systems bypass this extra step as the system can burn larger non-uniform particle sizes.

Fairbanks, Alaska has great potential to utilize cofiring due to the fact that five power plants in the area utilize 600,000 tons of coal per year. As Nicholls pointed out in previous work, there is a large amount of defensible space clearings that could be used [3]. Fairbanks's power comes from mostly stoker-fired grate systems, which are the easiest to convert to managing cofiring. This is especially true when cofiring wood and coal in small quantities or with similar particle sizes; for example, wood chips and pea coal [5]. The objectives of this research were to examine the emissions and the feasibility of cofiring aspen *(Populus tremuloides)* wood chips at the Aurora Power Plant in downtown Fairbanks.

## Literature Review

Previous cofiring in interior Alaska was completed multiple years in the 1980's [9]. Cofiring was done in 1984, 86, and 87 in the Fairbanks area. Cofire rates varied from 10% to 30% (wet weight basis). The study determined that cofiring was technically feasible, but in order for plants to adopt cofiring, the economic incentive would have to be present. Other primarily Alaskan research considered forest thinnings from the surrounding area as cofire material [4]. These thinnings were to be harvested to reduce wildfire risk in the Fairbanks woodland-urban interface.

A large majority of biomass cofiring has been researched using large scale pulverized coal power plants. One such study, has established large quantities of research on fuel handling and the effects of cofiring on emissions [3]. This study mainly analyzed $NO_X$ reduction, CO differences, and boiler efficiency of a variety of boilers. Tillman developed research on, approximately, a dozen different coal facilities. The testing demonstrated cofiring can be feasible over a wide variety of coal power plant technologies, biomass feedstocks, and geographic locations.

Although cofiring research internationally has been completed mostly utilizing large scale pulverized coal systems, several studies have also accomplished successful cofiring on grate systems. The Institute of Energy Technology in Denmark has produced a literature review with a top down overview of some of the challenges and advancements in cofiring with grate-fired systems [10]. The author claims that incomplete combustion can be reduced by pre-treating the biomass in a cofiring system or better controlling the combustion process. It is also claimed that more research needs to be developed to understand the combustion chemistry. China has been successful in cofiring at utility scale plants [11]. Here they were able to accurately measure flue gas compositions and boiler efficiency. For a test with 28-ton per hour fuel load, it was determined that boiler efficiency was 81.56% and NOx compounds were 257 ppm on average. Other tests have been accomplished monitoring specifically the fine ash and trace element emissions of cofiring [12]. This test was done with circulating fluidized beds and with municipal waste as the cofire material. Other test burns attempting to simulate travelling grates with stationary grates burning waste product have been successful in laboratory settings [13]. The study observed the effects of excess air on grate systems and discovered excess air in secondary zones of combustion can create additional NO production.

## Experiment Overview

### Challenges

A wide variety of variables must be considered when cofiring biomass and coal. Some of the variables include but are not limited to moisture content of the fuels, biomass percentage, plant operation, and fuel storage facilities.

One major dilemma facing cofiring is obtaining and procuring wood fuel of consistent size and moisture content. This is important because fuel quality impacts all aspects of the fuel burning process. Before burning, the fuel has to be delivered. Particle size and type could affect how much fuel a truck or train would be able to hold. A smaller, more uniform particle size may be able to be transported better than hog fuel, which is not a consistently sized fuel. This also affects the ability to store the biomass at the facility. Fuel that hasn't been processed down to a consistent size would take up a large amount of the yard space relative to bulk coal or processed chips/fine wood powders. This presents another difficulty with using wood fuel. Wood takes energy to process it to a high quality product and therefore can be expensive to use on a large scale. Creating high quality wood fuel at an economically feasible cost is a major challenge.

If higher levels of biomass are being utilized, large storage areas are generally needed to be built to contain the fuel. Additional storage and sorting facilities become required. Tillman shows examples of very large (200MW) facilities using very fine wood dust as cofire material [3]. These facilities needed large scale grinders and rotary grates for sorting the material. Acres of land were used to store all the material. For plants like Aurora, located in the heart of Fairbanks, space is much more limited. This could require additional infrastructure to store fuel. However, wood could potentially be delivered readily from the nearby wood pellet mill as required, reducing the need for the additional infrastructure.

The quality of the fuel also impacts all aspects of the fuel burning process [14]. As mentioned above, transporting fuels of inconsistent types make it more challenging to handle, load, and unload around the plant. Unpredictable sizes of material could potentially clog grates, get stuck in conveyor belts, and negatively impact the mixture of fuel. Oversized or large pieces of fuel would increase the likelihood of problems. Fuel that has a large range of moisture contents will create inconsistencies in the combustion chamber. In turn, some fuel may fully combust much more rapidly than other fuel. This could potentially lead to variance in plant operation parameters, making the plant less efficient and creating an additional challenge for operators.

Mixing a consistent fuel blend proves to be one of the most challenging aspects of stoker system cofiring. In pulverized coal plants it is possible to have two separate injectors; one for coal and one for wood. These can be adjusted to feed biomass at a rate relative to the coal. In many stoker-fired operations, coal is conveyor fed into a bunker and then gravity fed into the combustion chamber. Generally, there is only one feed source; therefore it is challenging to determine the rate at which wood is being added to the blend. The bulk density and particle geometry of the wood and coal influence the mixing properties of the blend. An example of a poor mixture would be consistent coal density, with a large range of biomass sizes mixed in. This would make certain portions of the mixture contain more or less biomass relative to the rest of the fuel. In the combustion chamber, wood fuel will burn more rapidly than the coal. This causes a “swiss cheese” pattern of fuel on the grate and affects the dynamics of the air being fed through the grate. The issue of consistency could be countered with utilizing pellet fuel, but would need to be economical.

For stoker systems, the easiest way to get an acceptable mixture of wood is to mix the biomass and coal as it is transported inside the facility. This would more than likely be completed while moving the fuel to the bunker that will directly feed into the combustion chamber. The fuel will have to travel from its storage location, on conveyor belts, to the final bunker. In this scenario, the wood could be on one conveyor belt while the coal is on another. Each could be set to a certain speed to create the proper mix. The bulk density of the fuels would be very important in getting accurate measures of the cofire percentage, either by energy content or by mass. One problem that may be encountered with this approach is that fuel may settle while it is in bunkers or while it is being moved around. This could, again, cause inconsistent mixing in the fuel blend, but would be an unavoidable consequence of this blending scheme.

**Emissions from Combustion**

One main objective of cofiring is to reduce the release of pollutants to the air. The major pollutants regulatory agencies are interested in are sulfur compounds, lead, ozone, nitrogen compounds, carbon monoxide, carbon dioxide, and particulate matter. Sulfur compounds and nitrogen compounds are both known to create acid rain which is harmful to various environments. Usibelli coal, used in Interior Alaska power plants, has extremely low sulfur content (<.2%) [15], and therefore sulfur is not of concern in the scope of the study. Carbon monoxide is a concern because it can cause health issues even among healthy adults. CO can be an issue, especially, when an inversion layer is created in the atmosphere; which is common to Fairbanks, Alaska in the winter. Carbon dioxide is an emission that is considered a greenhouse gas. $CO_2$ has become of great interest to regulatory agencies due to its properties relating to climate change. It is a major emission from combustion sources. If biomass is burned, in some cases, it is considered a CO2-neutral fuel. The final emission that is of importance, is particulate matter. One way to examine what level of particulate matter is in a certain fume is to study the opacity. Opacity is the measure of how the visibility of a background is reduced by particulates in emissions. Particulate matter in the atmosphere can be harmful to humans and is of concern in an area such as Fairbanks, Alaska where a large number of low-efficiency wood stoves are used in residential homes.

**Stoker Systems Overview**

Traveling grate, or mechanical stoker, systems are the most common type of small scale (less than 50MW) energy production facility. There are two general types of systems. The first is a spreader stoker (Figure 1). This type of facility has fuel being fed into a rotor that throws, (i.e. “spreads”) the fuel across the combustion chamber in both dimensions across the width and length. A grate travels back towards the rotor and fuel is combusted from below. The second type is a gravity fed fuel system (Figure 2). Fuel is gravity fed from a hopper into a conical; a cone shaped apparatus that spreads the fuel out over the entrance to the grate. The burner used for this study was a conical fed fuel system.

Relating to cofiring biomass with coal, each system has its own set of challenges. For spreaders, fuel can clog the rotors. This would cause problems with the spreading mechanism. Variable sized biomass could adversely affect the rotors clogging. One advantage to the rotor spreader is that the fuel is distributed more evenly across the grate. In conical fuel spreaders, fuel fills a bucket to a certain, measured, level and then is dumped onto the conical. This is so the fuel can be metered properly and continually poured into the combustion chamber, primarily by gravity. The downside to that style of feed is that it makes for an inconsistent spread when fuel size varies. This could be poor for biomass cofiring, for the same reasons mentioned above.

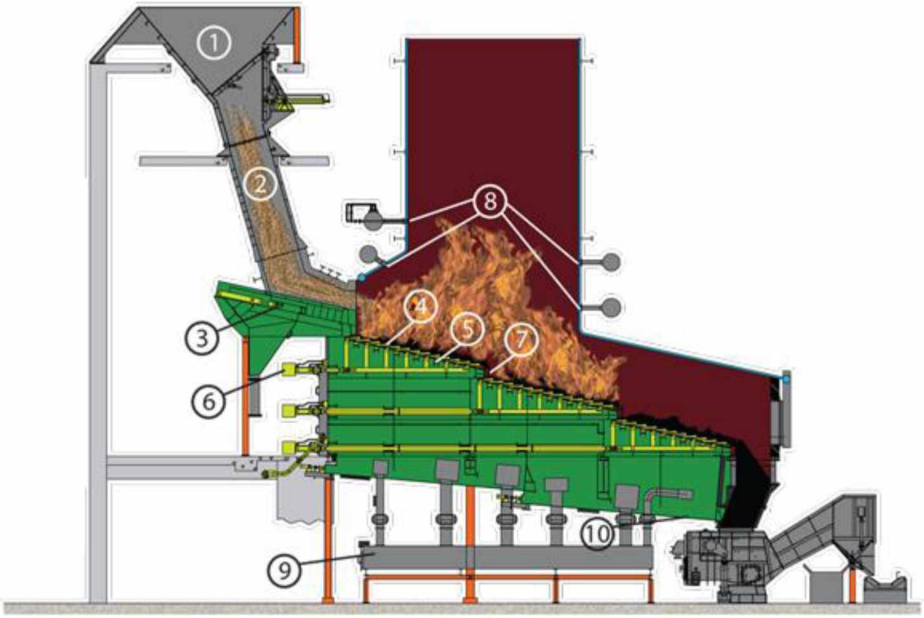


Figure 1: Gravity fed stoker grate combustion system [16]

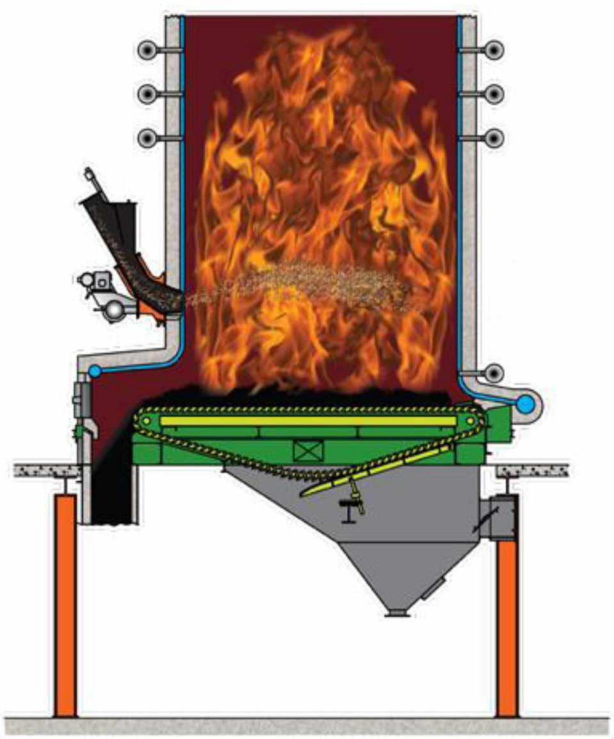

Figure 2: Rotor fed stoker combustion system [17]

## Methods

Our study goal was to evaluate two different cofiring rates on a local coal power plant in Interior Alaska. Based on the variety of research presented above our initial plan was to use a cofire rate of, approximately, 5% (by energy value) for the "low" and a 10-15% cofire rate for the "high" days. Composition of combustion gases were measured through the exhaust stack. Early attempts at research included even smaller scale facilities, such as private coal small scale coal burners. Problems pertaining to liability involved with modifying flue, for insertion of measuring probe, swayed us from one such location. Other problems include lack of interest from owners of coal burners, trouble contacting owners off the grid, and the challenge of finding people utilizing these types of systems. Ultimately, it was decided that the Aurora Power Plant was the best opportunity to study cofiring in interior Alaska. The Aurora Power Plant had previously partaken in cofiring railroad ties and showed great interest. The skilled operators managing the plant knew what to expect and were ready to take on the task.

### Aurora Power Plant

Test burns for the scope of this project were performed at the Aurora Power Plant in downtown Fairbanks, Alaska. The facility has a 32 MW nameplate power capacity. The Aurora Power Plant sells up to 25MW to Golden Valley Electric Association, which is the local utility. Golden Valley Electric Association serves the Alaska rail belt; the largest grid system in Alaska (Figure 3). The rail belt is the system stretching from Fairbanks to Anchorage, and then south to Seward. The plant burns approximately 210,000 tons of coal per year. Coal is acquired via railroad from the Usibelli Coal Mine near Healy, Alaska. This generates about 180,000 MW-hours of electricity per year. In addition to electricity, Aurora provides steam and hot water for a district heating system for downtown Fairbanks. This system includes approximately 15 miles of buried pipeline and services approximately 50 buildings [18].

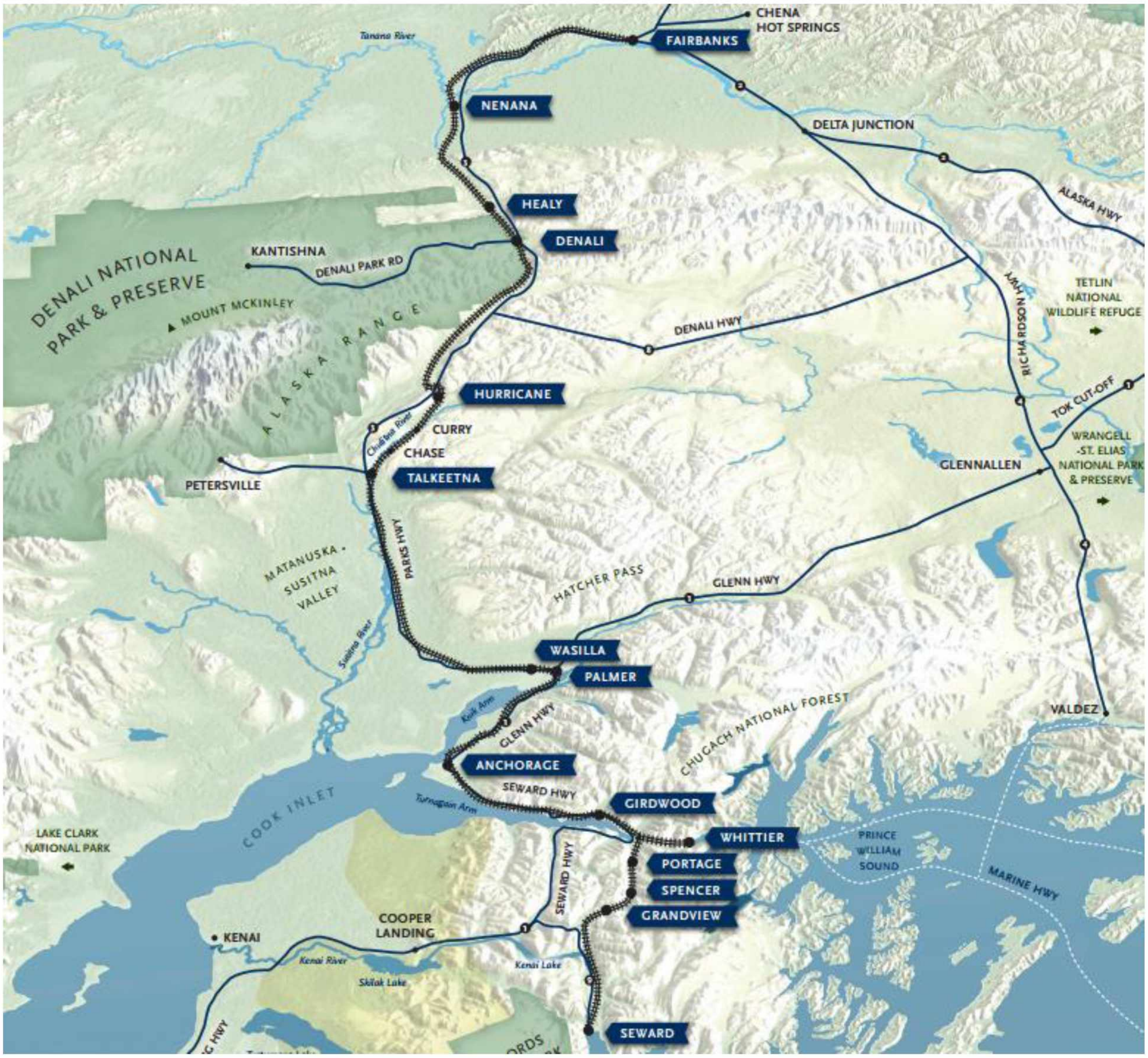


Figure 3: Map of the Alaska Railbelt [19]

## Cofiring Tests

In this study, biomass, in the form of clean, uniformly sized aspen (*Populus tremuloides)* chips, was cofired at the Aurora Power Plant in Fairbanks, Alaska. (Figure 4) Wood chips were provided by Superior Pellet Fuels in North Pole, AK. Approximately 40 tons of chips were purchased at $70/ton. Chips were approximately 1.5' and smaller. They were trucked directly from the pellet mill to the power plant (approximately 8 miles). Usibelli coal is the primary fuel used at the Aurora Power Plant. This fuel is delivered, by rail, from the mine in Healy, AK. Usibelli coal is purchased from the mine for approximately $50-70/ton.

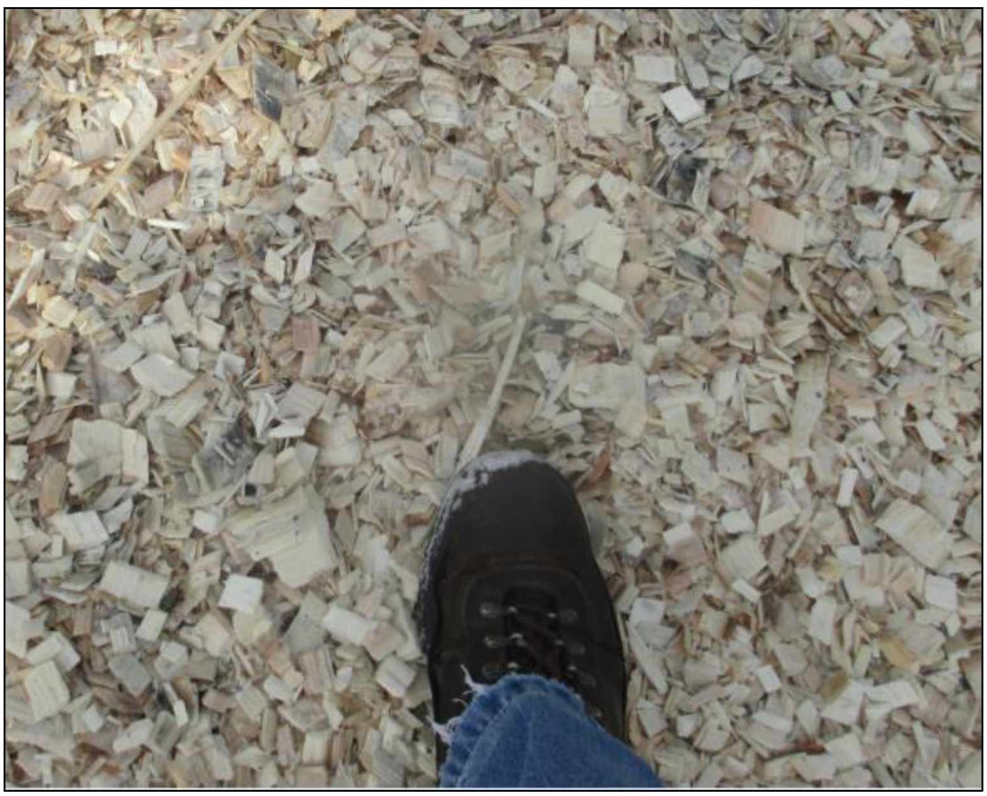

Figure 4: Aspen wood chips used in testing (photo credit Dave Nicholls)

Storage of the wood was a main concern for tests such as these, as discussed above. Fortunately, the power plant had adequate storage for the wood chips in their yard for the type of short-term testing performed. (Figure 5). The wood chips consumed approximately 800 sq. ft. of yard space. A front end loader was used to transport the chips to desired location and fuel feed system. Conveyer belt systems and storage hoppers located inside the actual plant were used to mix the fuel to the desired ratios of wood and coal. (Figure 6)

Figure 5: Wood Storage at Aurora Power. Front end loader used to move wood shown.

Figure 6: Wood chips mixed with coal travelling through the facility (credit Dave Nicholls)

A BACHARACH PCA 3 portable combustion analyzer was used to collect data. The PCA 3 is capable of logging $O_2$ percentage, CO in parts per million (ppm), CO (with respect to $O_2$) in ppm, Efficiency in percentage, $CO_2$ in percentage, and Excess Air in percentage. This probe was directly inserted into the stack (Figure 7). The probe was well sealed, as can be seen from the figure, to allow minimal outside air to reach the sample. The 12 inch probe did not reach the center of the 56 inch flue, but it is believed after comparison to Aurora Power's 28 inch gas probe that it provided an adequate representation of the gas.

A Testo combustion analyzer was provided by Aurora Power. As mentioned above, the Testo used a 28 inch probe to reach the center of the flue. The entry point for the probe was also very well sealed to prevent outside air from reaching the sampling point. This unit was used to measure $NO_x$ in ppm, as well as individual NO in ppm and $NO_2$ in ppm; along with the same parameters as the PCA 3. Opacity was also measured using regular plant equipment. The PCA 3 device took readings every 2 minutes for the duration of the test burns. The Testo measured in 30 second increments. The Testo probe can be seen in the background of Figure 7.

Figure 7: BACHARACH PCA3 inserted into combustion flue gas stack

**Results**

The results presented were obtained on the 17th and 18th of March, 2015. The “low” cofire testing was performed on day 1 and the “high” was executed on day 2. Baseline data was collected for approximately one hour each morning. Baseline data was acquired by burning a 100% coal fuel. The blended fuel (coal with biomass) was introduced shortly after the baseline readings had been collected. Target co-fire rates were 5% for the low co-fire day (day 1) and up to 15% for the high co-fire day (day 2), however actual rates were lower (Table 1). Cofiring rates were determined by collecting samples of fuel immediately before entering the conical.(Figure 8)

Figure 8: Sample being collected for determining cofiring percentage

Wood and coal were separated and weights of each were determined. Calorimetry was performed on the aspen wood chips in order to approximate the heat content of the material. Coal energy content was provided from the plant. Actual cofire rates are presented below.

| | Sample Time | Chips by Mass (%) | Chips by Energy Content (%) | Average Co-fire Rate (by Energy) |
|---|---|---|---|---|
| 3/17/2015 Day 1 "Low" | 11:19 | 6.60 | 4.47 | 2.40% |
| | 12:45 | 2.37 | 1.58 | |
| | 14:00 | 1.75 | 1.16 | |
| | 15:00 | 3.51 | 2.35 | |
| | 16:00 | 3.62 | 2.42 | |
| 3/18/2015 Day 2 "High" | 12:30 | 8.06 | 5.78 | 4.81% |
| | 13:30 | 6.14 | 4.38 | |
| | 14:30 | 9.24 | 6.65 | |
| | 15:30 | 6.53 | 4.66 | |
| | 16:30 | 3.66 | 2.59 | |
| | 17:30 | 2.05 | 1.45 | |
| | 18:30 | 0.47 | 0.33 | |

Table 1: Actual Cofire Rates

**Day 1: "Low" Cofire Tests**

"Low" cofiring testing was performed on March 17, 2015 (Day 1). As mentioned above, an attempt to cofire at a rate of 5% was made. The true cofire rate was approximately 2-3%. Baseline data was collected for an hour, from 0815 to 0915. Testing was performed for approximately 4.5 hours, from 1115 to 1600. Below is a schedule of events from the day.

| March 17, 2015 Test Schedule | |
|---|---|
| Baseline Data Collection Start | 8:15 |
| Baseline Data Collection Finish | 9:15 |
| Bunker Begins Filling with Wood/Coal Mixture | 10:15 |
| Wood Reaches Grate (approx.) | 11:15 |
| Cofire Data Collection Start | 11:30 |
| Final Cofire Data Collection | 16:00 |

Table 2: Day 1 schedule

All graphs presented feature a solid line representing the mean. The dashed lines represent the mean plus or minus one standard deviation.

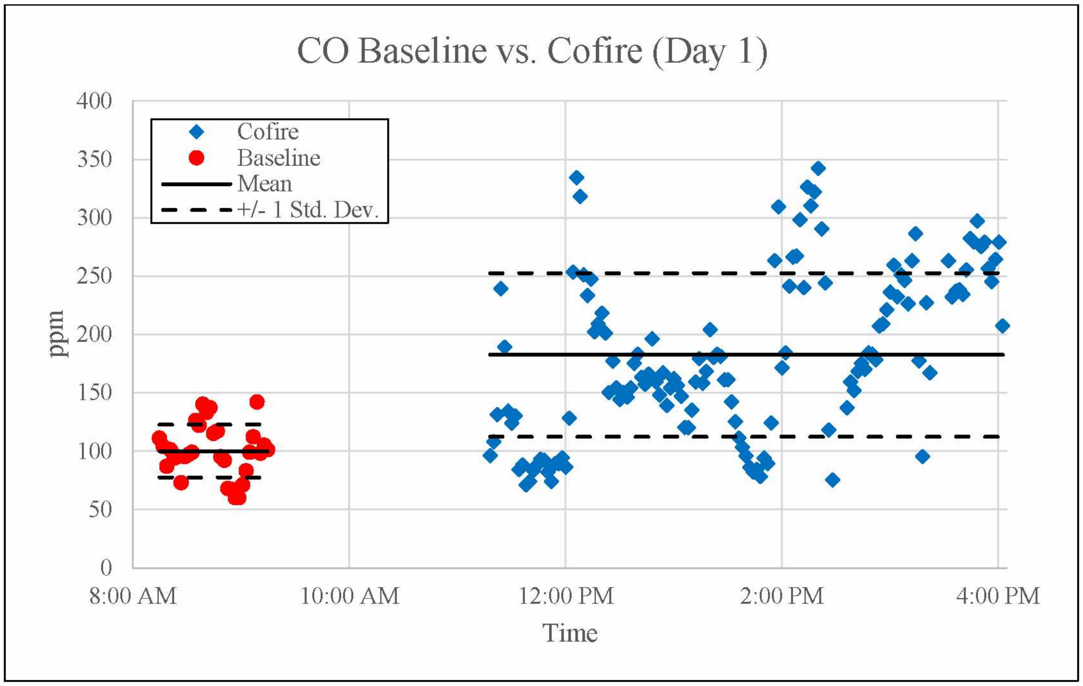


Figure 9: CO measurements plotted versus time from day 1

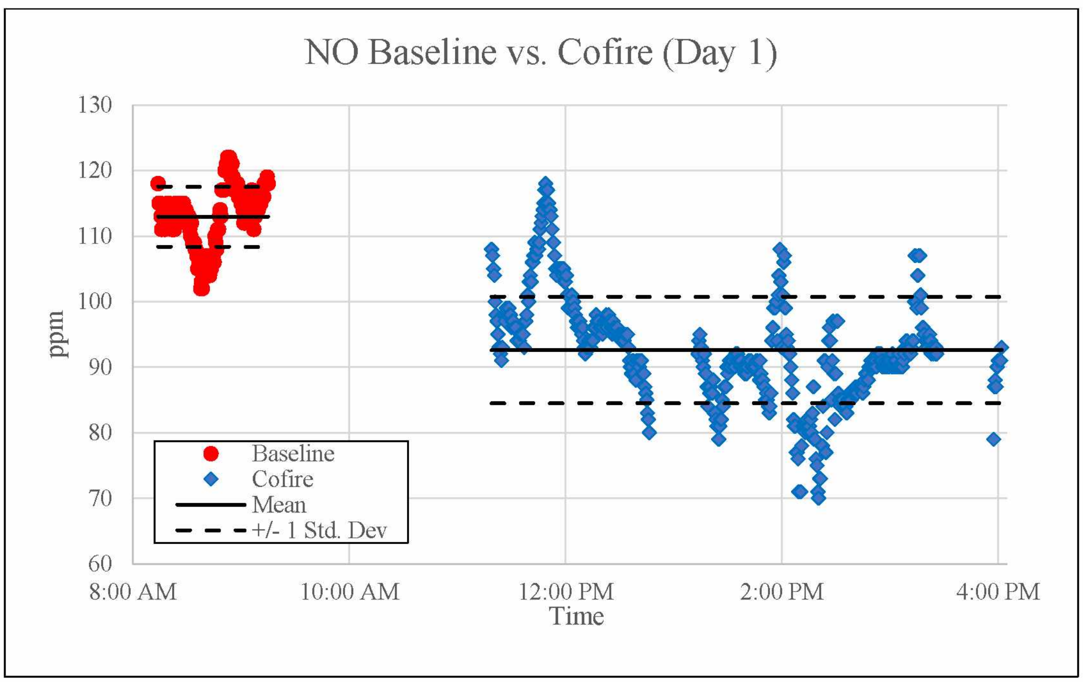


Figure 10: NO measurements plotted versus time from day 1

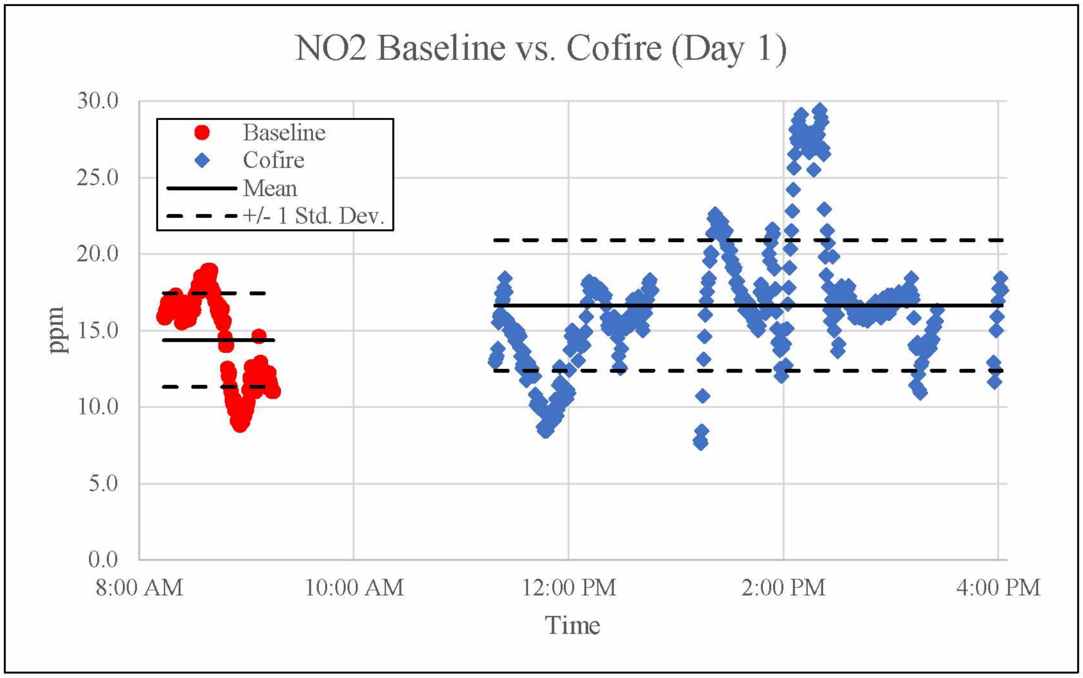


Figure 11: $NO_2$ measurements plotted versus time from day 1

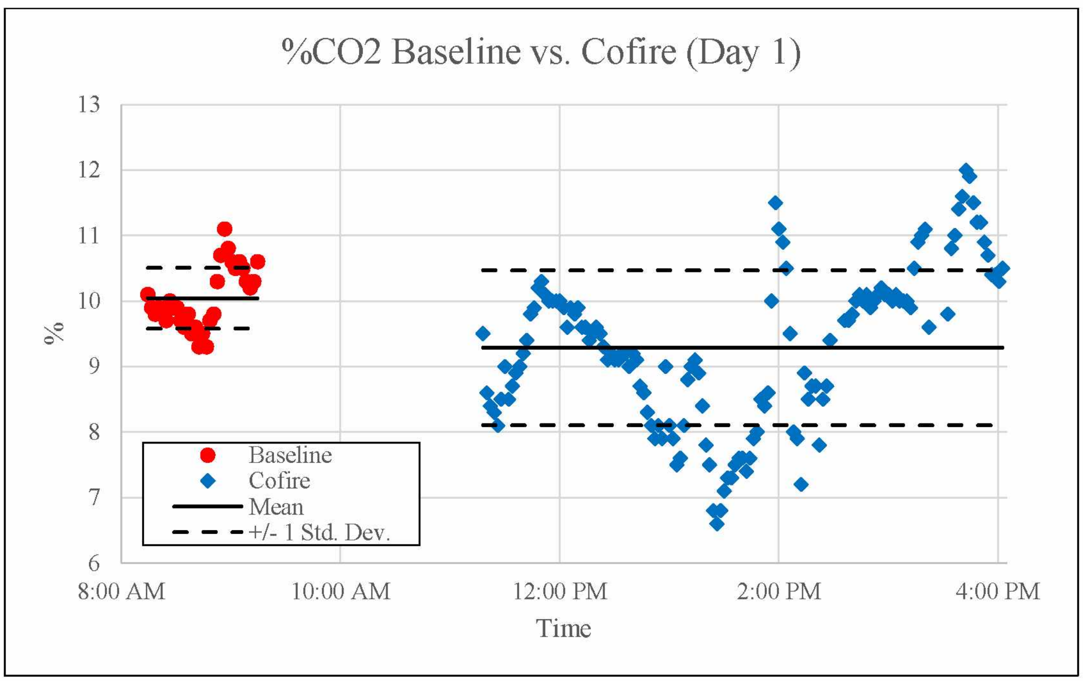


Figure 12: $CO_2$% measurements plotted versus time from day 1

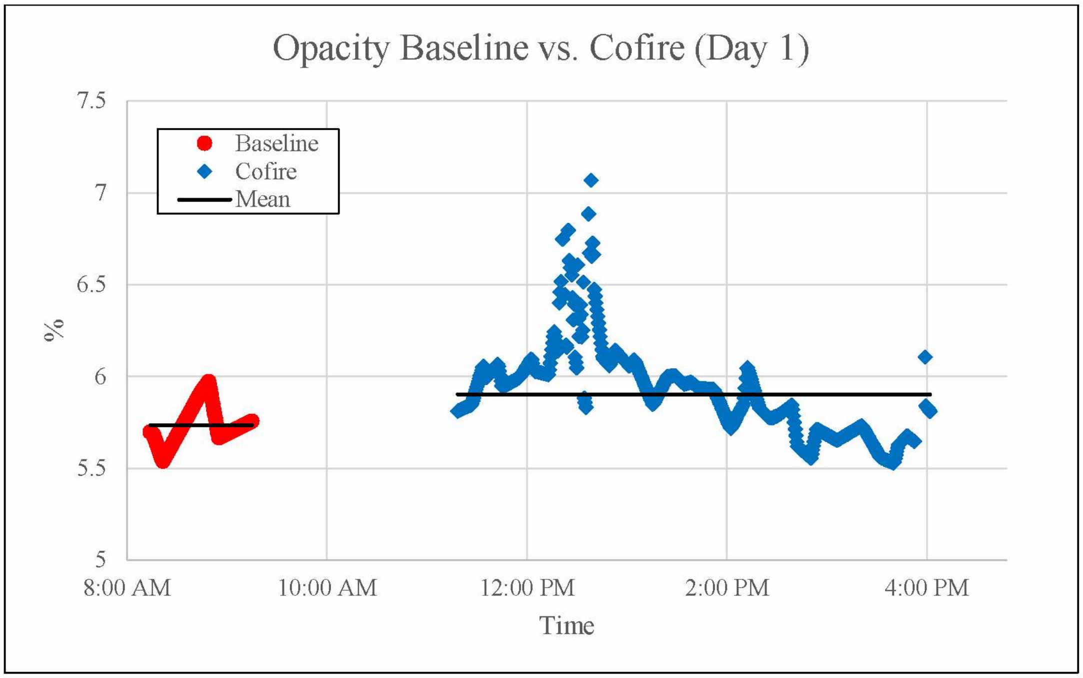


Figure 13: Opacity measurements plotted versus time from day 1

The measurements of CO and $CO_2$ were collected with the portable PCA-3 unit, while the NO and $NO_2$ was measured by the Testo unit. Opacity was measured by stock plant equipment. Below is a comparison of the means for the collected data from Day 1.

| Day 1 Mean Comparison | | | |
|---|---|---|---|
| | Baseline | Cofire | Percent Change |
| CO (ppm) | 100 | 182 | +82% |
| CO2 (%) | 10.0 | 9.3 | -8% |
| NO (ppm) | 113 | 93 | -18% |
| NO2 (ppm) | 14.4 | 16.6 | +16% |
| Opacity (%) | 5.7 | 5.9 | +3% |

Table 3: Day 1 mean comparisons

The first obvious difference between the baseline and the cofire data is the amount of CO increased by 82.4%, or 82.4ppm. $CO_2$% actually decreased by 7.5%, or 0.75ppm. NOx compounds decreased by a combined 18.05ppm. NO decreased by 20.3ppm, while $NO_2$ increased by 2.3ppm. The opacity increased by 2.9%.

**Day 2: “High” Cofire Tests**

“High cofire testing was performed on March 18, 2015. An attempt was made to have around 10-15% wood chips, by energy content. In reality, we only cofired at a rate of around 4-5% on average. Baseline data was collected from 0845 to 0945. Cofire testing data was collected from 1215 to 1800. Below is a schedule for the day.

| March 18, 2015 Test Schedule | |
|---|---|
| Baseline Data Collection Start | 8:45 |
| Baseline Data Collection Finish | 9:45 |
| Bunker Begins Filling with Wood/Coal Mixture | 11:20 |
| Wood Reaches Grate (approx.) | 12:30 |
| Cofire Data Collection Start | 12:45 |
| Final Cofire Data Collection | 18:00 |

Table 4: Schedule for day 2

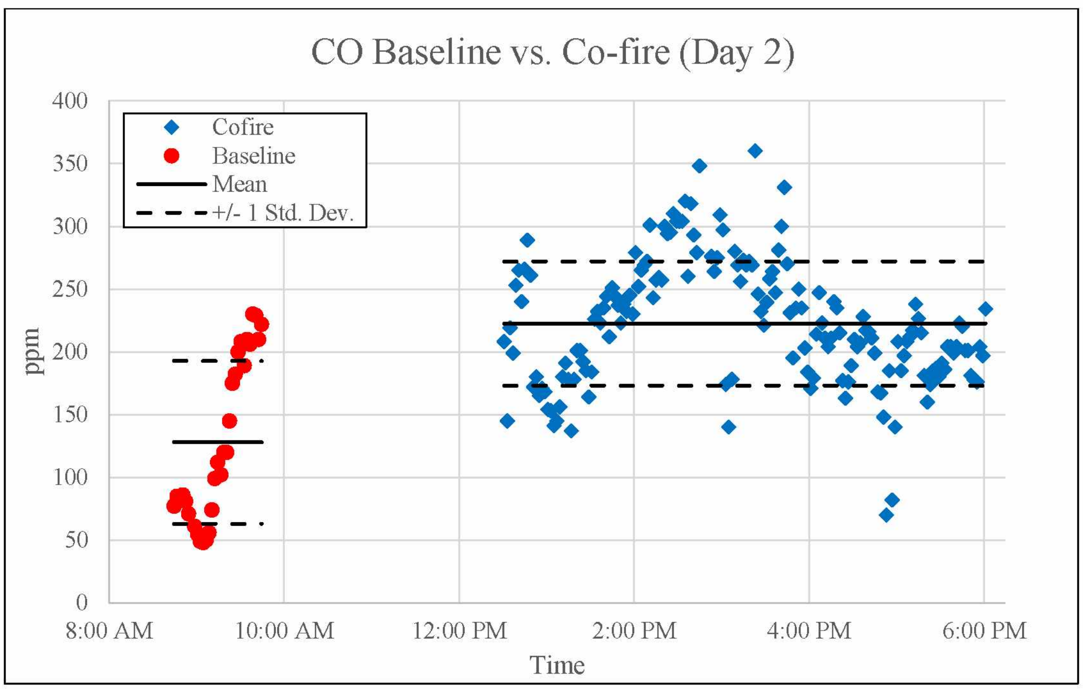


Figure 14: CO measurements plotted versus time from day 2

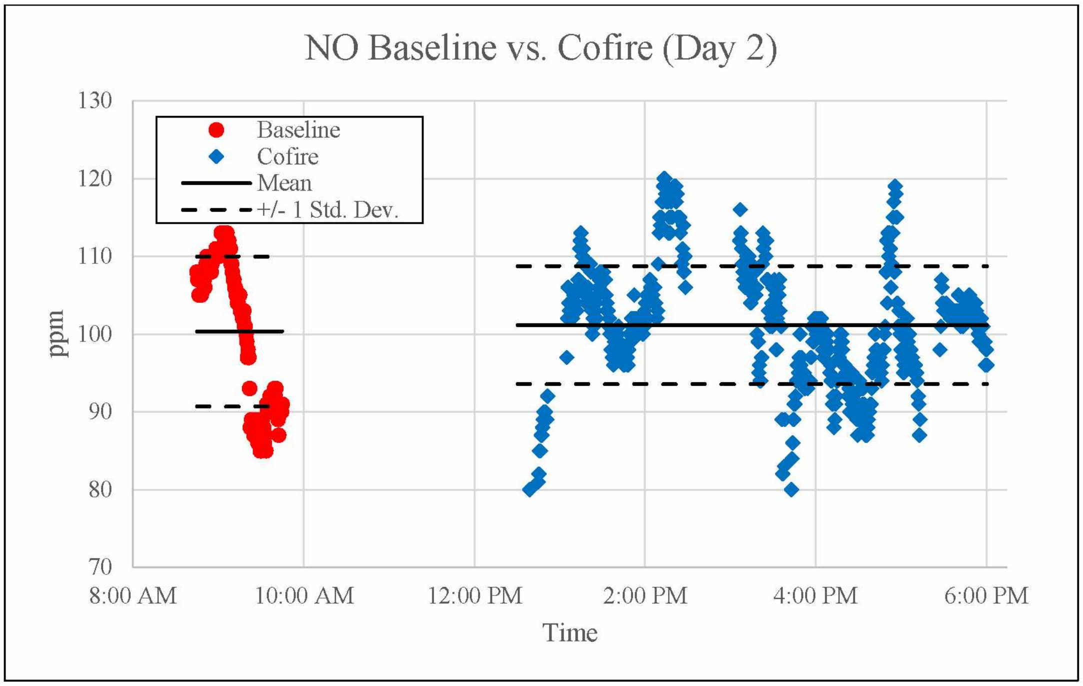


Figure 15: NO measurements plotted versus time from day 2

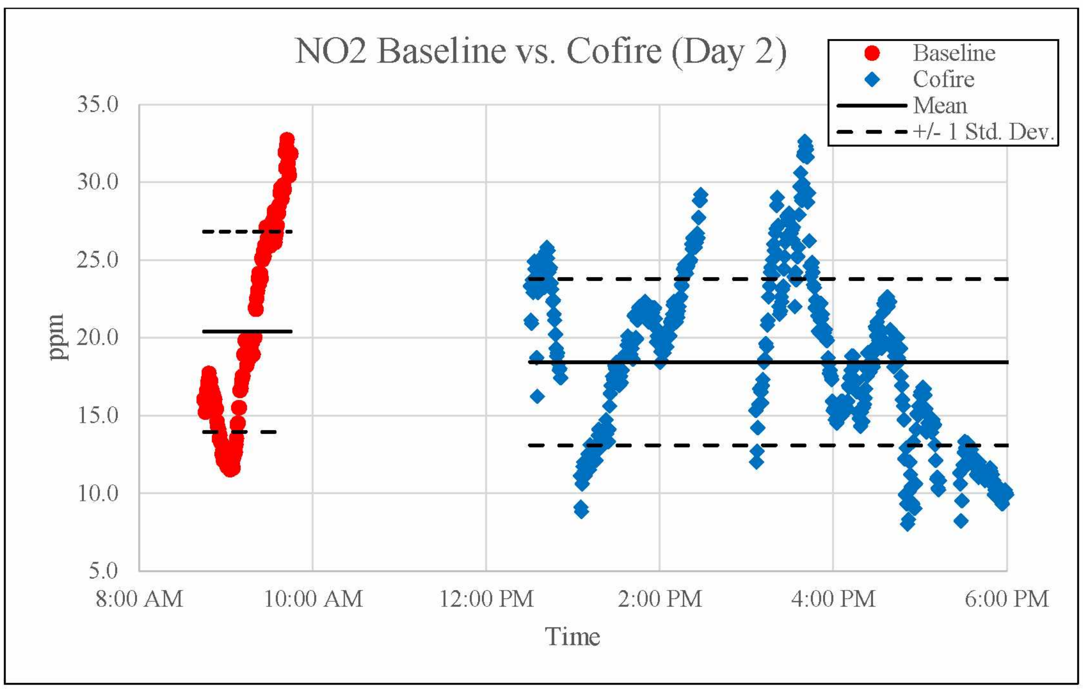


Figure 16: $NO_2$ measurements plotted versus time from Day 2

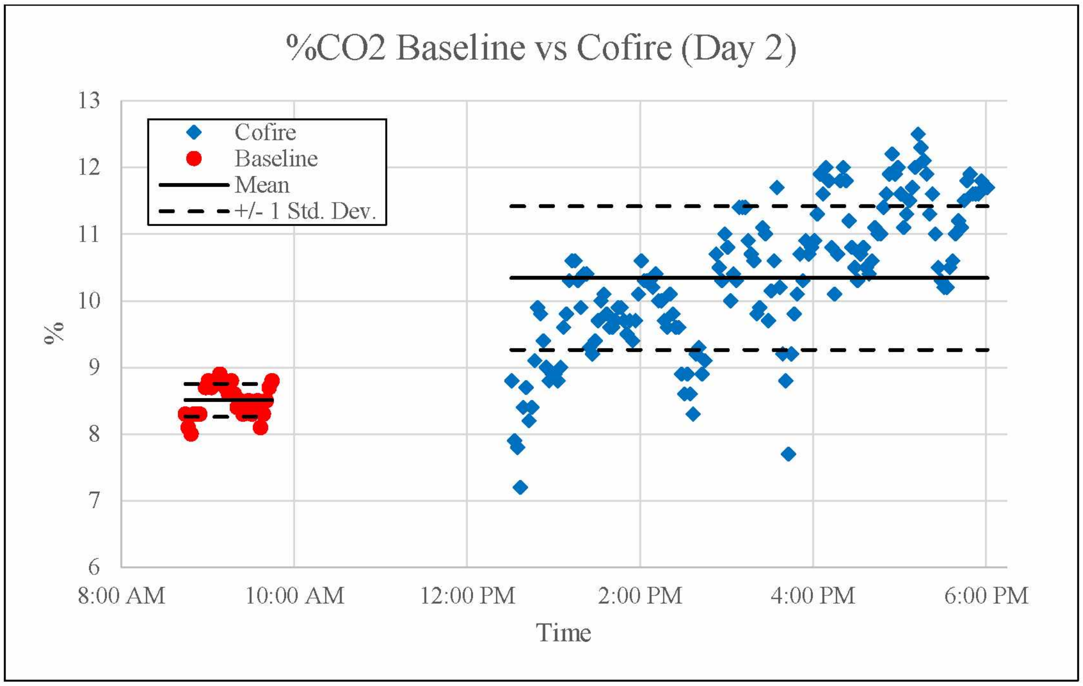


Figure 17: %$CO_2$ measurements plotted versus time from day 2

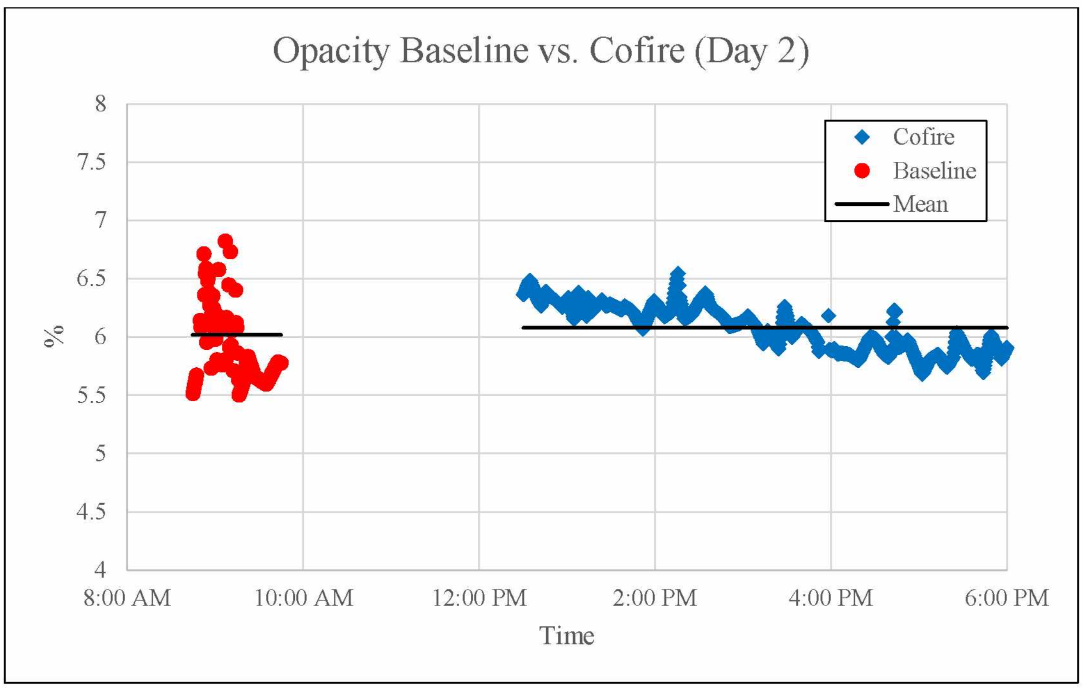


Figure 18: Opacity measurements plotted versus time from Day 2

The measurements of CO and $CO_2$ were collected with the portable PCA-3 unit, while the NO and $NO_2$ was measured by the Testo unit. Opacity was measured by stock plant equipment. Below is a comparison of the means for the collected data from Day 2.

| Day 2 Mean Comparison | | | |
|---|---|---|---|
| | Baseline | Cofire | Percent Change |
| CO (ppm) | 128 | 222 | +74% |
| CO2 (%) | 8.5 | 10.3 | +22% |
| NO (ppm) | 100 | 101 | +1% |
| NO2 (ppm) | 20.4 | 18.4 | -10% |
| Opacity % | 6.0 | 6.1 | +1% |

Table 5: Day 2 mean comparisons

During the Day 2 cofire tests, CO increased by 74%, or 95ppm, when compared to the baseline readings. The percentage of $CO_2$ in the gases increased by 22%. The NOx compounds decreased from 120.4ppm to 119.4ppm. This is a reduction of 1%. Opacity, also, increased by 1%.

## Discussion

The results from the testing at Aurora Power show a few similarities between the low cofire test and the high cofire test. The first major similarity is that CO increased significantly with the addition of biomass to the fuel. On Day 1, the average CO measured increased from 100ppm for the baseline test to 182ppm during cofiring; an 82% increase. On Day 2, the average CO measured increased from 128ppm, during the baseline recording, to 222ppm during cofiring. This indicates an increase in incomplete combustion. Another similarity between the two tests was the opacity. The mean opacity increased, although only slightly, on both days when wood fuel was introduced to the mixture. During the low cofire test the opacity increased from 6.0% to 6.1%. On the high cofire day, opacity increased from 6.0% to 6.1%. This preliminary observation indicates that burning biomass could potentially have a minimal effect on the opacity of the flue gasses. Other variables had much more inconsistent results. The mean $CO_2$ on day 1 decreased from 10% to 9.3% when biomass was introduced. This is a percent change of 0.75%. On the second day, however, mean $CO_2$ increased from 8.5% to 10.3%; a percent change of 1.8%. For $NO_x$ compounds, there was a net decrease each day. On day 1, $NO_X$ decreased from 127ppm to 109ppm. NO decreased from 113ppm to 93ppm and $NO_2$ increased from 14.4ppm to 16.6ppm. Day 2 saw a smaller decrease, from 120.7ppm to 119.6ppm. NO increased from 100ppm to 101ppm and $NO_2$ decreased from 20.4ppm to 18.4ppm.

Overall, plant operation went very smoothly with the introduction of biomass into the fuel mixture. The Aurora Power Plant facilitated the cofiring testing with one of their most experienced operators. The operator made the following observations. On the first day (low cofire rate), the plant burned the fuel very well with no issues and no major adjustments. On the high cofire day, he noticed that combusting the fuel was more of a challenge. This was attributed to the moisture content of the wood fuel. The wood fuel moisture content was estimated at around 30-40%. Another thing the operator noted was that the distribution of fuel was very uniform. This is more than likely attributed to small quantities of wood. The amounts of foreign fuel were not enough to displace the coal and cause excess settling. This also means the conical did a good job of distributing fuel to the grate. Overall, plant operation was not affected. Plant steam production data showed minimal changes throughout the testing. Both days feature very linear fits ($R^2 > .99$) when comparing cumulative steam produced and time, indicating that steam production was not affected by the alternate fuel. After the cofire testing was completed, the plant had no problem burning the remaining wood fuel left in the yard. This is a testament to the fact that burning biomass fuel is not a problem at stoker fired plants.

An attempt to discover the overall efficiency of the boiler was made, but a faulty scale provided incorrect coal quantities for each day. The discovery was made by plant employees after all testing had been completed. In future testing, a different scale would be used. This scale did not affect the amount of biomass added to the coal fuel.

## Conclusion

The testing performed at the Aurora Power Plant demonstrated that cofiring small amounts of biomass with coal is technically feasible. A key objective of the research was to determine the challenges of cofiring Alaskan biomass and coal in the average stoker fired system. Alaskan aspen chips were purchased, transported to the facility, and used as fuel simultaneously with coal. No physical modifications were made to the plant. There were also no significant problems encountered because of the addition of biomass to the fuel. Plant operators simply made adjustments and continued to produce steam and electrical power. It must be noted, though, that the testing performed was done under ideal conditions. The wood burned was processed specifically for these tests and purchased at a price that is not economical for wide spread use at this time. Aspen chips were purchased for approximately $7.04/MMBtu, which is more than double what Usibelli coal costs the plant (~$3.30/MMBtu). Utilizing a fuel that is more economical, such as scrap wood, may not be as simple and would be a more advanced test. Aurora Power coordinated to do these tests when their most experienced operator was on shift. A less experienced operator may not know how to manage the conditions brought by a moist wood fuel. Operators must be ready to pay more attention than normal to how the wood fuel is effecting the chamber to avoid any complications. Ultimately, the major finding of this study was verifying what many past studies have shown; that cofiring is technically feasible at low wood ratios. In the case of the Aurora Power trials, we also demonstrated the technical feasibility of site-specific factors including fuel transportation, storage, and fuel mixing. Given these results, and the ease of executing cofiring trials, we expect that cofiring low wood ratios would also be feasible at other Fairbanks area power plants. The other plants around Fairbanks are all of similar size to Aurora Power, all are grate systems, and all use the same Usibelli coal, which is assumed to be similar size and heating value.

Another objective of the research was to measure the combustion gases of the plant and attempt to analyze the effect of cofiring on the emissions. From a logistics standpoint, collection of emissions data was very easy. The plant also supplied their own measuring equipment for the stack; which was also a very straightforward set-up. Future analysis could be done the same way without a problem. One item of note from the testing completed is that neither probe is designed for extended use in a combustion stack. Each probe needed to be purged occasionally leading to some of the gaps in the data. One of the observations made during testing was the increase in CO. Increases of 82% and 74% were observed on days 1 and 2, respectively. It is likely due to the high moisture content of the aspen chips resulting in less efficient combustion. In the case of $NO_X$, we saw reductions of 1ppm on day 1 and 18ppm on day 2. Another observation made was that opacity of the combustion gases changed very little. A change of 0.17% was observed on day 1, and a change of 0.06% on day 2. This indicates that burning biomass may or may not increase the opacity of the exhaust. With more investigation, this could potentially be an important finding that is useful for plants under scrutiny in the form of opacity measurement. Realistically, longer term testing must be performed to establish statistical evidence of cofiring's effect on emission fumes.

**Future Testing**

While the testing discussed above shows that the use of biomass fuel in a stoker fired plant is relatively easy, the tests leave a variety of opportunity for further testing. As noted above, this testing was not done using an economical fuel. A better test would be to burn scrap wood or hog fuel such as forest thinnings or milling waste product that would normally go to waste. Hog fuel is fuel that has not been ground down to a specific size. The spruce chips used were made specifically for these tests and were not purchased at an affordable rate compared to coal. From a practical standpoint, cofiring low value hog fuel from area wood products facilities (such as the pellet mill in North Pole, AK) could hold great potential for economically cofiring on an ongoing basis. More work is needed to determine the delivered cost of hog fuel versus that of coal (on a $ per BTU basis), to determine whether market-based solutions can help increase levels of cofiring in interior Alaska. Defensible space harvests, brush, and land clearing byproducts are all forms of non-uniform fuel, however these fuels are often supplied sporadically. The advantage to utilizing non-uniform fuel is that more energy does not need to go into grinding the fuel to size, in turn, making it cheaper. Combined with small scale facilities, hog wood fuel could be a cheaper and useful alternative.

An excellent follow up to this study would be to cofire biomass at a consistent percentage for multiple tests. Cofiring at a certain percentage for multiple days, or months, would allow better statistical observations. An attempt to measure the true mean values of $CO_2$ and $NO_X$ at a certain cofire rate could be made with more certainty. Plant operators would also have more time to fine tune the plant systems for utilizing the biomass fuel. This in turn would make the test results possibly more consistent. Cofiring of this type would more than likely require special permitting from the state of Alaska and potentially more rigorous Alaska Department of Environmental Conservation (DEC) involvement. Procuring enough wood for long scale testing could also be a problem depending on what is available for reasonable prices at the time of testing. Longer scale cofiring tests would also offer the advantage of closer examination of conditions such as “slagging and fouling”, potential corrosion issues, and differences in ash content between cofiring and coal-only combustion. By cofiring a range of wood fuel types, moisture contents, and cofiring ratios, it could be possible to determine those fuel blends that would minimize some of the problems sometimes associated with cofiring.

Finally, another interesting test would be to cofire biomass and coal at smaller scale facilities (<10MW). A few of these facilities exist around Alaska. Exploring cofiring in these facilities could potentially give owners another option if inexpensive wood waste product became available in their communities. This could possibly encourage other people in communities to convert to an alternative fuel if they see a small operation is utilizing the technology. For cofiring at small facilities (involving small amounts of wood), users would most likely need to locate a steady supply of inexpensive wood waste, perhaps from a nearby sawmill or land clearing operation.

Utilizing wood for energy generation in Alaska has great potential. As shown above, the potential to improve the emissions being put out by coal fired power plants exists. No barriers for cofiring at low levels were found throughout the study. This conclusion would likely hold true for similar facilities in interior Alaska. The major challenge becomes obtaining wood fuel at an affordable cost. Various potential biomass supplies exist throughout interior Alaska that could be used. If biomass usage was adopted on a wider scale, an inventory of available resources would most definitely need to be performed, but this would allow production facilities to cofire at a sustainable rate. By putting fuels that are sustainable to use, Alaska would be taking more initiative on renewable energy as well as making a positive impact on emissions.

## Appendix

Calorimetry was performed using a Parr Series 1341 Plain Jacket Oxygen Bomb Calorimeter. This calorimeter utilizes ASTM Standard Test Method D5865, "Standard Test Measurement for Gross Calorific Value of Coal and Coke." Below is the resulting calorimetry curves for aspen chips.

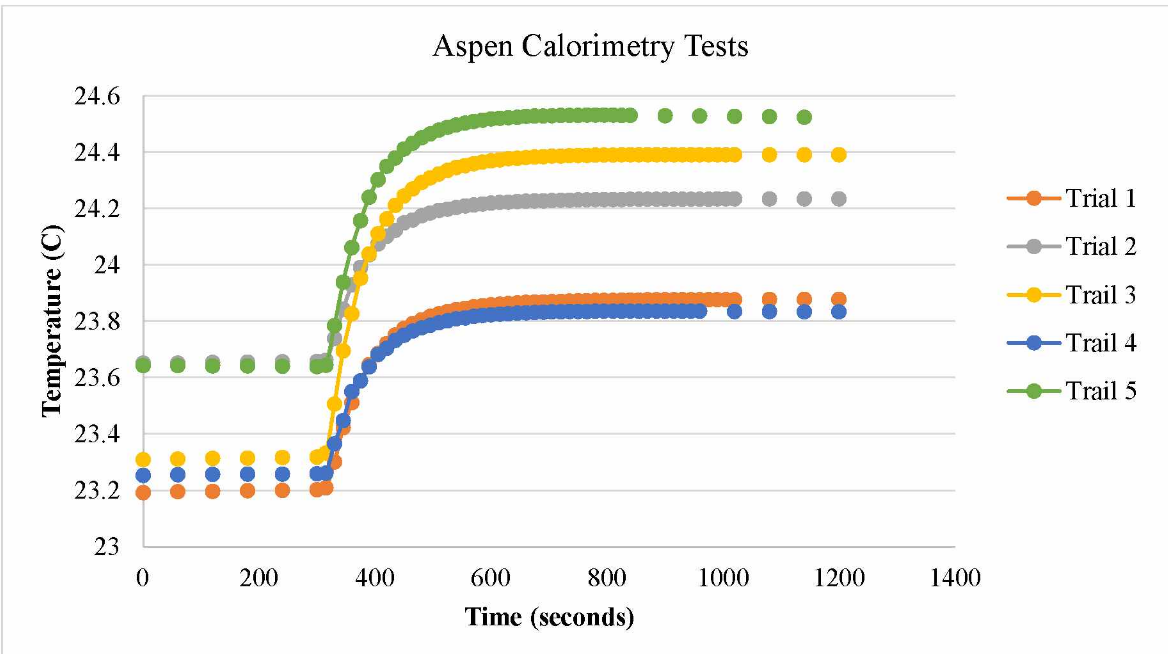


Figure 19: Aspen Calorimetry Samples

## References


[1] McDowell Group, "Energy and the Economic Impacts of Coal in Interior Alaska," McDowell Group, Anchorage, 2013.

[2] U.S. Department of Energy, "U.S. Energy Information Administration," 29 April 2015. [Online]. Available: http://www.eia.gov/energyexplained/index.cfm?page=electricity_in_the_united_states. [Accessed 2 May 2015].

[3] D. A. Tillman, "Cofiring Biomass with Coal," Foster Wheeler, Clinton, New Jersey, 2001.

[4] D. L. Nicholls, S. E. Patterson and E. Uloth, "Wood and Coal Cofiring in Interior Alaska: Utilizing Woody Biomass From Wildland Defensible-Space Fire Treatments and Other Sources," United States Department of Agriculture, Portland, Oregon, 2006.

[5] Biomass Cofiring in Coal-Fired Boilers, Washington, DC: Department of Energy, Federal Energy Management Program, 2004.

[6] P. Grammelis, G. Skodras and E. Kakaras, "Effects of biomass co-firing with coal on ash properties," *FUEL,* vol. 85, pp. 2310-2315, 2006.

[7] W. Amos, "Summary of Chariton Valley Switchgrass Co-Fire Testing at the Ottumwa Generating Station in Chillicothe, Iowa," National Renewable Energy Laboratory, Golden, CO, 2002.

[8] D. M. Boylan, "Southern Company Tests of Wood/Coal Cofiring in Pulverized Coal Units," *Biomass and Bioenergy,* vol. 10, no. 2-3, pp. 139-147, 1996.

[9] G. R. Sampson, A. P. Richmond, G. A. Brewster and A. F. Gasbarro, "Cofiring of Wood Chips with Coal in Interior Alaska," *Forest Products Journal,* vol. 41, no. 5, pp. 53-56, 1991.

[10] C. Yin, L. Rosendahl and S. K. Kaer, "Grate-Firing of Biomass for Heat and Power Production," *Progress in Energy and Combustion Science,* vol. 34, no. 6, pp. 725-754, 2008.

[11] Z. Li, W. Zhoa, R. Li, Z. Wang, Y. Li and G. Zhoa, "Combustion Characteristics and NO Formation for Biomass Blends in a 35-ton-per-hour Travelling Grate Utility Boiler," *Bioresource Technology,* vol. 100, pp. 2278-2283, 2009.

[12] T. Lind, J. Hokkinen and J. K. Jokiniemi, "Fine Particle and Trace Element Emissions from Waste Combustion- Comparison of Fluidized Bed and Grate Firing," *Fuel Processing Technology,* vol. 88, no. 7, pp. 737-746, 2007.

[13] T. Rogaume, F. Jabouille and J. Torero, "Effect of Excess Air on Grate Combustion of Solid Wastes and on Gaseous Products," *International Journal of Thermal Sciences,* vol. 48, pp. 165-173, 2009.

[14] S. V. Loo and J. Koppejan, The Handbook of Biomass Combustion & Co-firing, London: Earthscan, 2008.

[15] Usibelli Coal Mine, "Coal: Data Sheet," [Online]. Available: http://www.usibelli.com/Coal-data.php. [Accessed April 2016].

[16] D. S. System. [Online]. Available: http://www.detroitstoker.com/main/detroit-stokers-reciprograte/.

[17] Detroit Stoker Company, "Detroit Stoker Company," 2012-2016. [Online]. Available: http://www.detroitstoker.com/main/detroit-stokers-rotograte/. [Accessed 2016].

[18] B. Wright, "Alaska Power Association 59th Annual Meeting: Aurora Energy, LLC," Usibelli Coal Mine, Inc, Fairbanks, 2011.

[19] Alaska Railroad, "Alaska Railroad," 2016. [Online]. Available: https://www.alaskarailroad.com/ride-train/route-map. [Accessed 2015].